An Improved QuikSCAT Weekly Wind Data Set for Coastal and High Latitude Applications

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INTRODUCTION The SeaWinds instrument on the QuikSCAT satellite has measured global marine winds since 1999. However, microwave backscatter from land and ice limits the coverage and utility of QuikSCAT wind measurements near land and at high latitudes. We developed a new QuikSCAT weekly wind data set with several improvements that address these limitations to the existing data. The improved QuikSCAT data set includes new land and sea ice mask information adapted from the AVHRR Pathfinder sea surface temperature (SST) v5.0 and the Optimally Interpolated SST v2 data sets, respectively. Additionally, missing near shore and ice margin pixels contaminated by backscatter from land and/or ice have been estimated by an objective analysis technique. The gap filling method for QuikSCAT wind data was then evaluated against in situ wind speed and direction measurements taken from marine weather stations. We discuss here the improvements in the new QuikSCAT weekly wind data set and statistical comparisons with the in situ wind data.

METHODS We generated weekly mean wind fields for the ascending and descending passes, as well as a combined field that is the mean of ascending and descending. To each weekly averaged QuikSCAT image, a new land mask adapted from the AVHRR Pathfinder SST v5.0 data[1] set was added in order to differentiate between land pixels and those that contain water contaminated by microwave backscatter. A sea ice mask was incorporated from the Optimally Interpolated SST v2 data set[2] in order to differentiate water from sea ice (Figure 1). Remaining missing pixels were filled by an objective analysis technique similar to Kriging[3].

The objective analysis estimates the missing wind anomaly with a weighted mean of surrounding wind anomalies and adds the estimate back to a weekly climatology. The estimate of the missing wind anomaly, v, is the sum of w_i*v_i, where i=1,..,n and w_i are the weights given to the wind anomaly v_i at pixel i (sum of weights is 1). w_i can be obtained by solving the linear system C·w=D, where w is the weights vector and C and D are the following covariance matrices (at right):

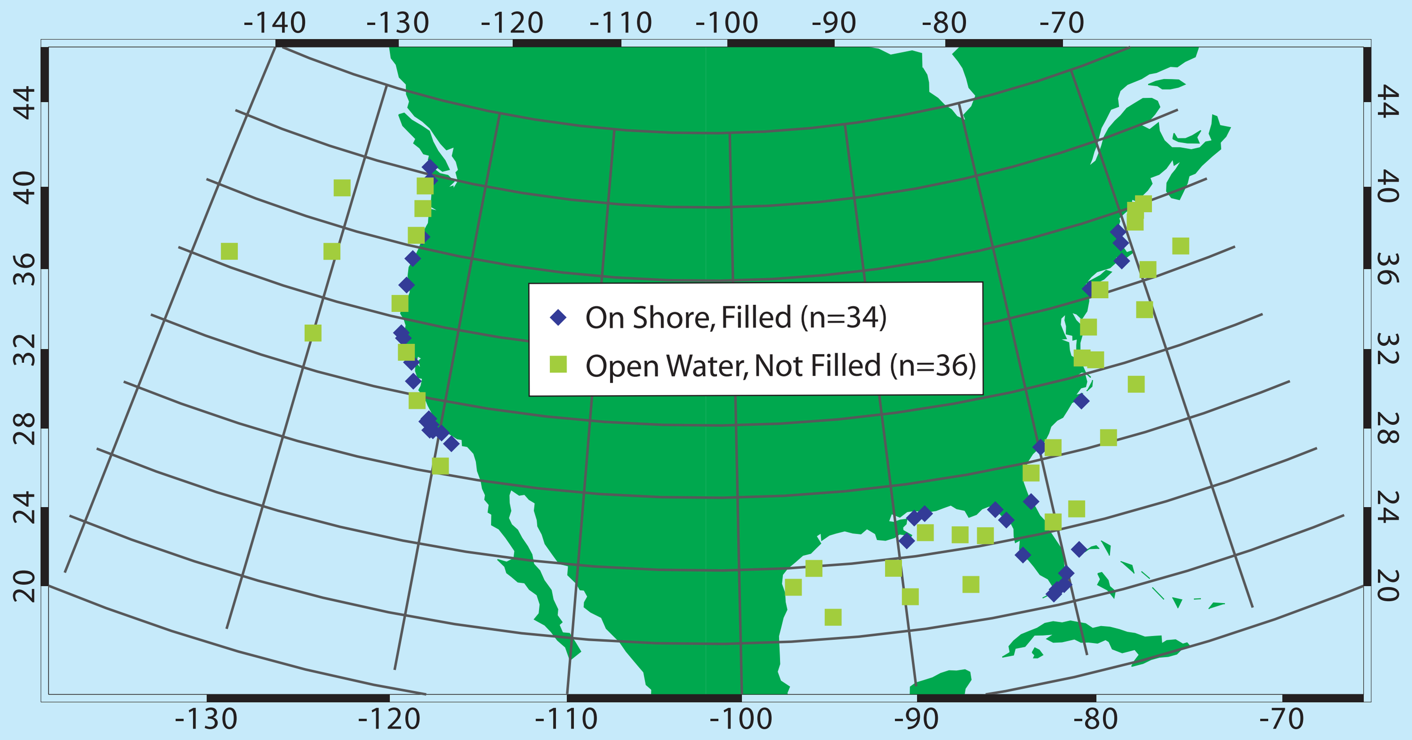

Figure 3 Map shows the location of filled (blue diamond) and unfilled (green square) locations with coincident in situ wind data. In situ wind data are from the National Data Buoy Center[4].

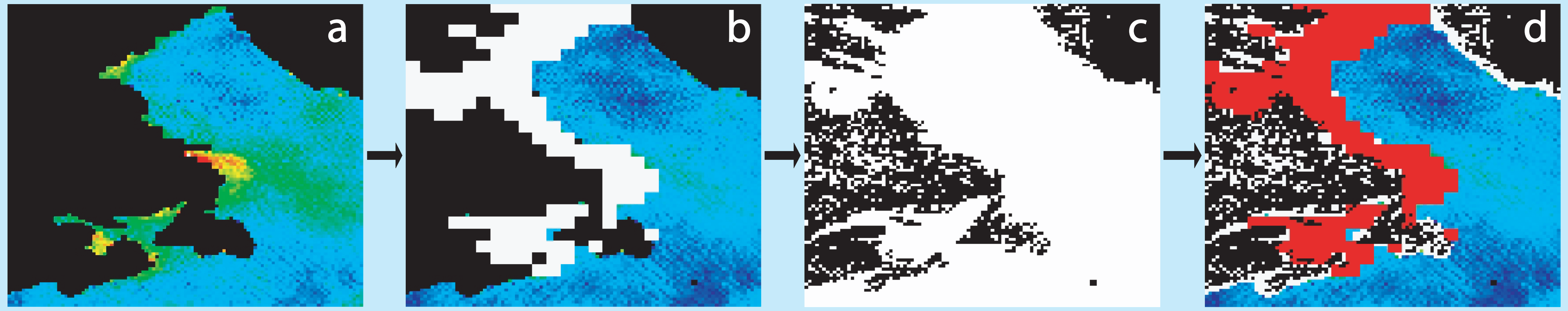

Figure 1 The new QuikSCAT weekly wind data set incorporates improved land and sea ice mask information, as well as gap filling of coastal and near sea ice zones that were missing in original QuikSCAT data. Looking from left to right shows how land, sea ice, and QuikSCAT pixels contaminated by backscatter are identified. Figure 1a is a QuikSCAT weekly wind speed average (3rd week of February 2004) for the Labrador Sea, with no masking added. Figure 1b is the same QuikSCAT image, but with the sea ice mask added (ice is white, land is black). Figure 1c is the AVHRR Pathfinder SST land mask (land is black, water is white). Figure 1d shows the icemasked QuikSCAT image with the Pathfinder land mask added. Ice is red, land is black, white values are the pixels that need to be filled with objective analysis, and all other values represent valid wind speeds.

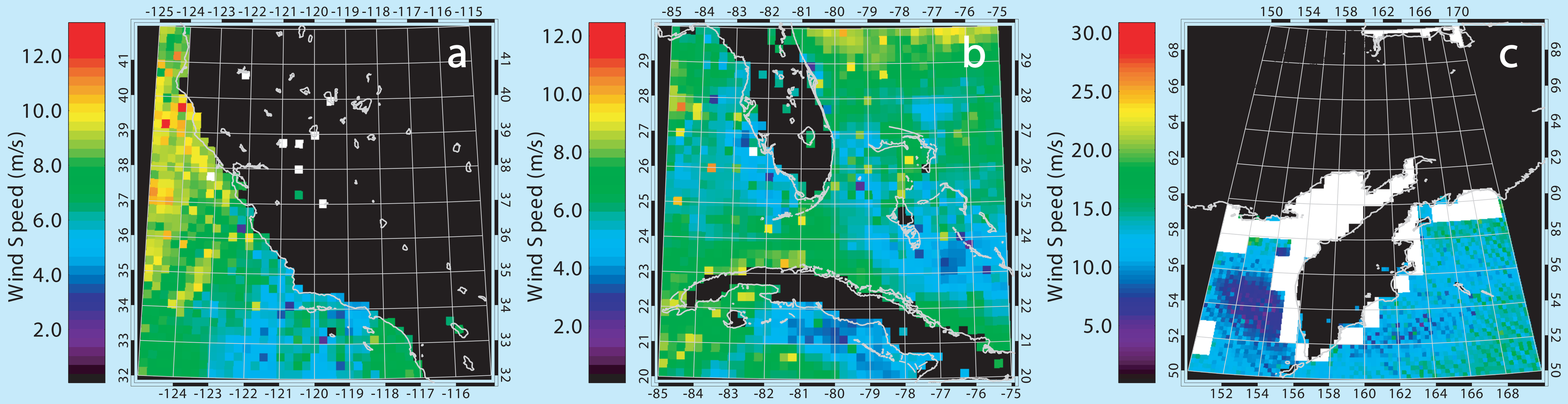

Figure 2 These three weekly combined (ascending and descending passes averaged) mean wind speed images for week 3, February 2004 show the improvements in the QuikSCAT weekly wind data set. In Figure 2a, you can clearly see that wind speed values have been calculated for near shore--and in some cases lacustrine--pixels along the West Coast of the United States. The white values in the interior are places where the filling algorithm could not produce reasonable estimates. In Figure 2b, the reefs in the Florida Keys and Bahamas have satellite coverage where they generally did not in the original QuikSCAT data. In Figure 2c, sea ice is shown surrounding the Kamchatka Peninsula of Russia.

$$C=\begin{bmatrix} C_{11} & \cdots & C_{1n} & 1 \\ \vdots & \ddots & \vdots & \vdots \\ C_{n1} & \cdots & C_{nn} & 1 \\ 1 & \cdots & 1 & 0 \end{bmatrix} \qquad D=\begin{bmatrix} C_{10} \\ \vdots \\ C_{n0} \\ 1 \end{bmatrix} \qquad w=\begin{bmatrix} w_1 \\ \vdots \\ w_n \\ \mu \end{bmatrix}$$

We used an isotropic, exponential model for the covariance structure in the weekly averaged fields: $C(h)=C(1)\exp(-3h/\alpha)$, where C(h) is the covariance at distance h and α is the length parameter. We fit, in a least squares sense, the autocovariance in the longitudinal and latitudinal directions to the equation to determine C(1) and α. Finally, an estimate of the model error variance can be calculated from the following equation:

$$\sigma^2_{mod} = \sigma^2_{max} - \sum_{i=1}^{n} w_i * C_{i0} + \mu$$

where σ^2_{max} = C(1) and C_{i0} and μ come from vectors D and w. Figure 2 shows example images.

VALIDATION We compared QuikSCAT weekly wind values to 70 collocated coastal weather stations (Figure 3) to assess the bias, defined here at the mean of the differences between the QuikSCAT and in situ wind speed time series, and the RMSD of the satellite and in situ wind time series. 34 stations fell on filled pixels and 36 on unfilled pixels. The wind speed biases between the QuikSCAT and in situ locations were positive and significant for filled and unfilled locations (Table 1; see reference[5] and appendix[a]), indicating that QuikSCAT overestimates wind speed (Figure 4). Filled wind speed biases are significantly higher than unfilled locations, though this may partly be due to real geophysical differences between near shore and open open stations. u and v components of wind biases are generally not significant, though the RMSD are large, suggesting that error in directionality may be a problem in the weekly averages. Interestingly, wind direction bias for the filled locations is significantly lower than for the unfilled locations (Table 1).

Figure 4 Time series of wind speed and u and v (east and north are positive u and v) wind components are shown for Sombrero Reef, Florida (81.1° W, 24.6° N) in the top panel of each plot. The lower section shows twice the estimated model error standard deviation. A noticeable positive bias is apparent in the QuikSCAT wind speed measurements, while the u and v components do not show a clear bias. Overall, the filled QuikSCAT wind data show remarkable agreement with the in situ reference data.

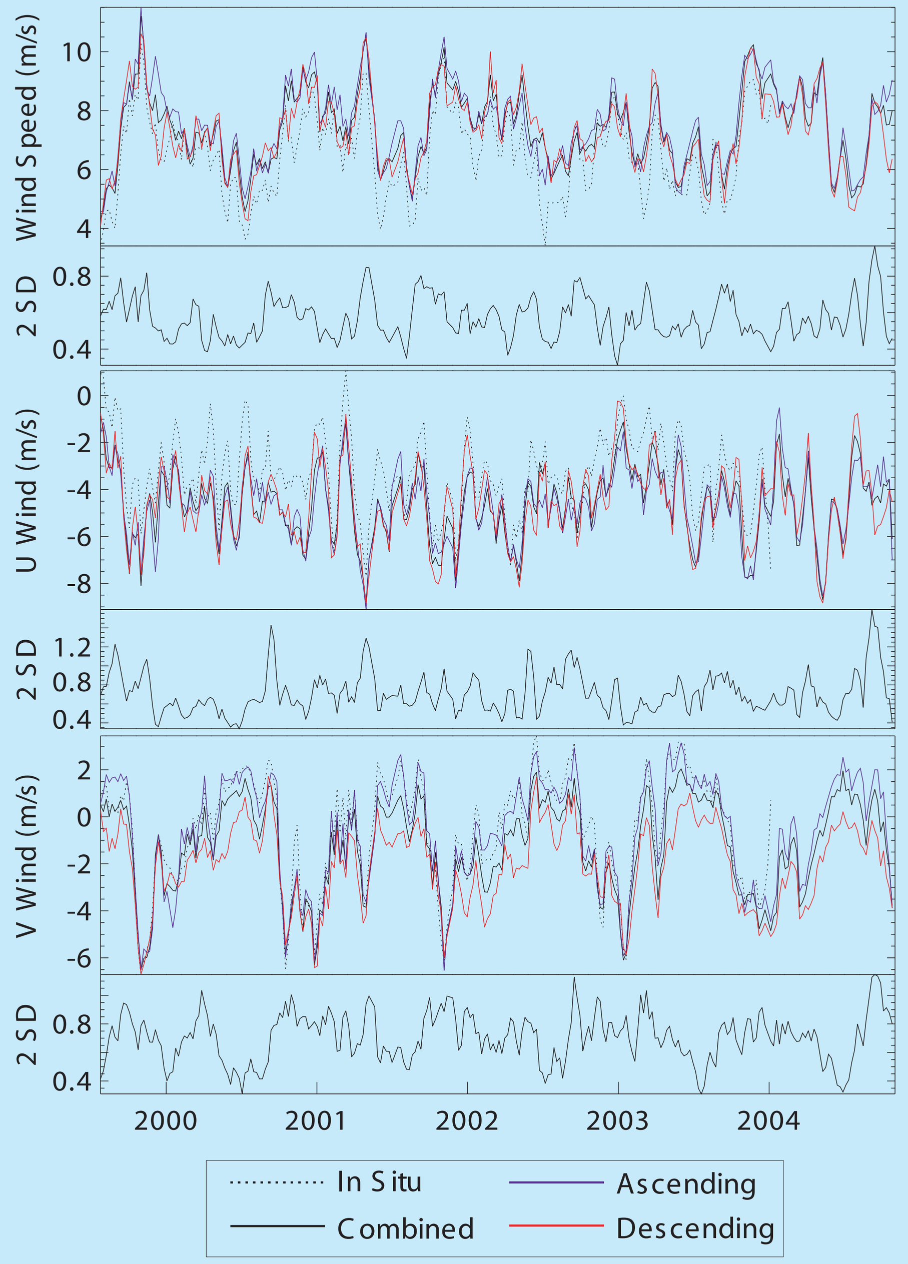

Table 1 Mean bias and mean RMSD for wind speed and u and v components for the combined, ascending, and descending passes are shown in Table 1. The numbers in parentheses indicate the percentage of the in situ locations that displayed a significant bias. There were a total of 70 in situ locations; 34 were gap filled and 36 were not. The final column indicates with a simple 'Yes' or 'No' whether the biases between unfilled and filled locations are significantly different (see appendix[b]). Wind speed biases, for both filled and unfilled locations are positive and significant. Wind direction biases, however, are generally not significant.

Variable	Satellite Pass	Mean Filled Bias	Mean Filled RMSD	Mean Unfilled Bias	Mean Unfilled RMSD	Filled and Unfilled Biases Different?
Wind Speed	Comb	1.49 (92)	2.04	0.86 (92)	1.51	Y
	Asc	1.44 (88)	2.09	0.93 (92)	1.82	Y
	Des	1.49 (91)	2.15	0.80 (92)	1.74	Y
U Wind	Comb	0.15 (38)	1.96	0.04 (17)	2.36	Y
	Asc	-0.07 (35)	2.13	0.13 (31)	2.6	N
	Des	0.39 (47)	2.19	-0.09 (11)	2.61	N
V Wind	Comb	-0.98 (3)	2.28	-0.49 (0)	3.09	Y
	Asc	-0.94 (3)	2.36	-0.61 (6)	3.29	N
	Des	-1.05 (15)	2.61	-0.44 (3)	3.32	Y
Wind Direction	Comb	36.18 (0)	50.53	51.89 (0)	68.25	Y
	Asc	39.69 (3)	54.22	54.98 (0)	71.14	Y
	Des	39.12 (3)	54.17	53.61 (0)	69.74	Y

CONCLUSIONS

- Weekly estimates of filled wind speed and direction are similar to unfilled pixels.
- QuikSCAT overestimates coastal ocean wind speed.
- Weekly estimates of wind direction for gap-filled pixels are better than non-filled pixels.

REFERENCES

[1] The landmask used in AVHRR Pathfinder SST v5.0 is based on MODIS's use of a 1 km resolution data set derived by the USGS Land Processes Distributed Active Archive Center. For more on the Pathfinder landmask process, see http://www.nodc.noaa.gov/sog/pathfinder4km/userguide.html.
[2] Reynolds RW, Rayner NA, Smith TM, Stokes DM, Wang W (2002) An improved in situ and satellite SST analysis for climate. J Climate 15: 1609-1625
[3] Isaaks EH and Srivastava RM (1989) An introduction to applied geostatistics. New York NY, Oxford University Press
[4] NOAA National Data Buoy Center, www.ndbc.noaa.gov
[5] Wilks DS (1995) Statistical methods in the atmospheric sciences. San Diego CA, Academic Press

APPENDIX

[a] Statistical significance of highly correlated QuikSCAT and reference buoy wind time series calculated after Wilks (1995). The high autocorrelation effectively reduces the number of samples in the time series and leads to an underestimate of the sample variance. For each time series, the effective number of samples, n', is equal to n*(1-p1)/(1+p1), where p1 is the lag1 autocorrelation for that time series and n is the number of samples. The test statistic can then be defined as: ((QuikSCAT mean)-(Buoy mean)) / ((QuikSCAT variance)/n'q+(Buoy variance)/n'b +2*p*(((QuikSCAT variance)/n'q)^0.5)*(((Buoy variance)/n's)^0.5)^0.5). In this case, p is the Pearson correlation coefficient between the QuikSCAT and in situ time series and n'q and n's are the effective number of samples for the QuikSCAT and in situ time series, respectively.

[b] To evaluate the difference between filled and unfilled mean biases, a simple test for comparison of means was used where the test statistic was equal to (mean(filled biases) - mean(unfilled biases))/((variance(filled biases)/n1) + (variance(unfilled biases)/n2)). n1 and n2 are the number of samples in each population.

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